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(54) Auditory prosthesis with user-controlled feedback.

(57) Apparatus and method for canceling feedback in an auditory prosthesis. An input filter includes an adaptive filter which can be user activated to provide rapid adaption of the filtering characteristics. A probe generator may generate a predetermined signal to introduce a known component in the input signal via the feedback path during rapid adaption. The filter characteristics are adapted in response to a reference signal containing a component of the predetermined signal and a component of the output of the amplifier. An alternate embodiment adds to the reference signal an unwanted noise component taken from the input signal wherein the filter characteristics adapt to filter an unwanted noise in the input signal provided that adaption is actuated when the unwanted noise is predominant in the input signal. Both embodiments include a slow adaption mode wherein the filter characteristics are slowly adapted between intervals of rapid adaption to provide adjustments to gradual changes in the characteristics of the feedback path or the unwanted noise.

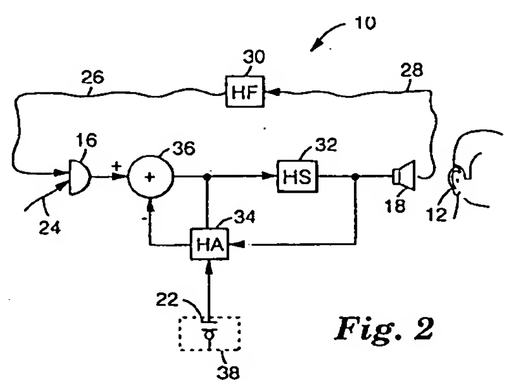

Fig. 2

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This invention generally relates to a method of and means for adaptively canceling feedback in an auditory prosthesis and, in an alternative embodiment, to a method and means for both filtering unwanted background noise and canceling feedback.

Most people are familiar with the screeching noises, generally high pitched, caused by acoustic feedback in public address systems. This feedback noise results when sound from the speaker of the public address system "feeds back" to the microphone and is further amplified resulting in an uncontrolled signal reinforcing feedback loop.

This same problem is familiar to the users of auditory prostheses, particularly hearing aids, as well. In hearing aids, sound from the speaker, receiver in hearing aid parlance, of the hearing aid sometimes finds its way back to microphone of the hearing aid either through the air, through the hearing aid housing or through the tissues, bone or cartilage of the user's ear or head. The screeching noise caused by such acoustic feedback in a hearing aid is a major irritation to the hearing aid user and can even be irritating to persons in their vicinity.

Conventionally, the user of a hearing aid controls unwanted acoustic feedback by reducing the gain on the amplifier in the hearing aid. This solution, however, is obviously counterproductive to the purpose of the hearing aid to amplify sound in the user's environment. Moreover, manual adjustment of the volume of a small hearing aid is sometimes difficult and inconvenient.

At least one proposed solution to this problem is set forth in U.S. Patent No. 4,783,818, Graupe et al. The Graupe et al '818 patent discloses a system which has a filtering circuit in front of the hearing aid amplifier which attempts to cancel feedback and prevent it from being reamplified. This system includes a filter adaption mode in which the amplifier of the hearing aid is switched out of the circuit and a random noise generator is energized to drive the receiver (speaker). The feedback cancellation filter is simultaneously activated in an adapting mode in order to adapt to cancel any feedback received by the hearing aid microphone from the receiver. The amplifier of the hearing aid is switched back into the circuit once the adaption of the filter is complete and the filter is returned to its filtering mode. The hearing aid is thus configured to provide cancellation of feedback as may be generated from amplifying sounds in the user's environment.

The filter adaption mode disclosed in the Graupe et al '818 patent is activated in response to system turn-on, or to other changes in the dynamics of the amplification system which indicate acoustic feedback. Initial system turn-on, which normally occurs in conjunction with the placement of the hearing aid in the user's ear, permits the system to adapt itself to the initial acoustic conditions of the fitting. Subsequently, changes in the dynamics of acoustic feedback can also trigger the adaption mode if certain predetermined criteria are met whereby the system can dynamically adapt to cancel feedback during the time the hearing aid is in use.

While the system disclosed in the Graupe et a '818 patent does provide some manner of adjustment to changing feedback conditions, the hearing aid is not operative to amplify sound while such adjustments are made. Consequently, the adaption mode interrupts the continuous listening by the user of the hearing aid. Moreover, the circuits which detect the need to readjust the system are limited to detecting a finite set of the possible conditions which may give rise to uncontrolled feedback amplification, thus rendering the system potentially insensitive to certain feedback conditions. Moreover, the circuits required to detect changing feedback conditions make the system relatively complex and expensive.

Another problem familiar to hearing aid users is the unwanted amplification of background noise which can partially mask the signal of interest to the user, which is typically speech. Various solutions to this problem have been proposed. In particular, U.S. Patent No. 4,025,721, Graupe et al, (and U.S. Patent No. 4,185,168, Graupe et al, a continuation-in-part of the '721 Graupe patent) discloses a system for filtering unwanted background noise from the input to the hearing aid amplifier wherein the input filter is designed to continuously adapt to the prevailing background noise in the user's environment. This system, however, may produce an unwanted and annoying "pumping" sound heard by the user. The cause of this "pumping" sound and the other problems with the system disclosed in the Graupe et al '721 patent are explained in the referenced co-pending application.

Summary of the Invention

As set forth below, the present invention provides an apparatus for user-controlled feedback cancellation which provides effective feedback cancellation and a method for doing same. The auditory prosthesis of the present invention allows adaption for effective feedback cancellation while not interrupting the normal amplification mode of auditory prothesis. Further, the auditory prosthesis of the present invention is flexible to be adaptable to whatever feedback situation which the user recognizes. By allowing the user of the auditory prosthesis the ability to control the adaptability of the prosthesis, a much greater degree of intelligibility

is provided to the adaption process. Only the user knows what is considered to be feedback or noise at a particular time. Further, what is considered feedback, or noise, at one time, may be desirable acoustic components in environment at another time. Also, the present invention sets forth, in another embodiment, an apparatus for combined feedback cancellation and background noise filtering and a method for doing same.

The present invention provides an auditory prosthesis adapted to be used by a person in an auditory environment having an original input component and having a feedback component originating from the auditory prosthesis. An input transducer produces an electrical input signal from the auditory environment. A signal processor processes the electrical input signal to produce a processed signal. A receiver receives the processed signal and converts the processed signal into an acoustic output signal. An input filter having an adaptive filter is coupled to the signal processor to cancel the feedback component from the electrical input signal using selectively adaptable filtering characteristics. A user controlled means coupled to the adaptive filter selectively causes the adaptive filter to adjust the adaptable filtering characteristics based upon the electrical input signal and the processed signal in response to the user.

In a preferred embodiment, the adaptive filter includes means for rapidly adapting the filtering characteristics at a first rate to provide for fast convergence until the filtering characteristics are nearly converged and then at one or more progressively slower rates to provide more accurate convergence until the characteristics are converged.

In another embodiment, the present invention provides an auditory prosthesis adapted to be used by person in an auditory environment having an original input component and having a feedback component originating from the auditory prosthesis. An input transducer produces an electrical input signal from the auditory environment. A signal processor for processing the electrical input signal to produce a processed signal. A receiver receives the processed signal and converts the processed signal into an acoustic output signal. An input filter having an adaptive filter coupled to the signal processor cancels the feedback component from the electrical input signal using selectively adaptable filtering characteristics. Probe means coupled between the signal processor and the receiver and coupled to the adaptive filter selectively generates a predetermined noise signal. A user controlled means is coupled to the adaptive filter and the probe means for selectively causing the probe means to generate the predetermined noise signal and causing the adaptive filter to adjust the adaptable filtering characteristics based upon the electrical input signal and the processed signal in response to the user.

In a preferred embodiment, the user operated control causes the probe generator to add the predetermined noise signal at a level which results a component of the acoustic output signal originating from the predetermined noise signal being inaudible to the user of the auditory prosthesis but strong enough to provide that the input signal contain a level of the feedback component sufficient for adaption of the filtering characteristics.

In an alternative embodiment, the present invention provides an auditory prosthesis adapted to be used by a person in an auditory environment having an original input component and having a feedback component originating from the auditory prosthesis. An input transducer produces an electrical input signal from the auditory environment An input filter cancels the feedback component from the electrical input signal to provide a filtered input signal, the filter operative to cancel the feedback component in accordance with a reference signal and having selectively adaptable filtering characteristics. A signal processor processes the filtered input signal to produce a processed signal. A delay delays the processed signal to produce a delayed processed signal. A receiver receives the processed signal and converts the processed signal into an acoustic output signal. Reference signal means obtains the delayed amplified signal and uses it to produce the reference signal. An adaptive filter coupled to the signal processor cancels the feedback component from the electrical input signal, the adaptive filter having selectively adaptable filtering characteristics. A user controlled means coupled to adaptive filter selectively causes the adaptive filter to adjust the adaptable filtering characteristics based upon the electrical input signal and the processed signal in response to the user.

In another alternative embodiment, the present invention provides an auditory prosthesis adapted to be used by person in an auditory environment having an original input component and having a feedback component originating from the auditory prosthesis. An input transducer produces an electrical input signal from the auditory environment. A filter receives the input signal and cancels a selected feedback signal component from the input signal in accordance with a feedback reference signal to produce a filtered input signal. A signal processor processes the filtered input signal to produce a processed signal. A first delay receives the processed signal and produces a delayed processed signal. A probe generator generates a predetermined signal. A first summing amplifier having programmable gain produces an output signal comprising a controlled mix of the signals. A receiver connected to the output of the first summing

amplifier produces an output sound corresponding to the output signal. A second summing amplifier produces a controlled mix of the signals. A second delay receives the output of the second summing amplifier and produces the feedback reference signal. User controlled means selectively generates a user actuated signal in response to the user. An adaptive filter connected to the input filter and the first and second summing amplifiers controls the adaption of the filtering characteristics of the filter, the adaptive filter including an input for the user actuated signal, the adaptive filter responsive to the user actuated signal for (i) causing the first summing amplifier to mix the predetermined signal into the output signal so that the input signal contains a known feedback component corresponding to the predetermined signal as introduced via the feedback path between the output transducer and the microphone, (ii) causing the second summing amplifier to mix the predetermined signal into its output so that the reference signal contains a delayed component thereof, and (iii) causing the filtering characteristics of the input filter to rapidly adapt in accordance with the known feedback component in the input signal, the feedback reference signal and an error signal taken from the filtered input signal so that the filtering characteristics are adapted to the characteristics of the feedback path whereby the input filter is operative to cancel feedback in the input signal.

In an alternative embodiment, the present invention provides an auditory prosthesis including feedback cancellation and noise filtering apparatus. A microphone produces an input signal. An input filter cancels a feedback component and an unwanted noise from the input signal to provide a filtered input signal, the filter operative to cancel the feedback component in accordance with a reference signal and having selectively adaptable filtering characteristics. An amplifier amplifies the filtered input signal to produce an processed signal. A delay delays the processed signal to produce a delayed processed signal. An output transducer connected to the delay produces an output signal corresponding to the delayed processed signal. Reference signal means obtains the delayed processed signal and uses it to provide the reference signal. Adaptive filter rapidly adapts the filtering characteristics of the filter in response to a signal actuated by a user of the auditory prosthesis. The adaptive filter includes a probe generator operative during the time of rapid adaption for adding a predetermined signal to the delayed processed signal to cause the output transducer to produce an output signal having a known component so that the known component travels through a feedback path to the microphone to provide that the input signal contains a known feedback component corresponding to the known component; means for obtaining from the probe generator a feedback reference signal corresponding to the known component and an unwanted noise reference signal from the input signal and adding them to the reference signal whereby the reference signal contains components corresponding to the delayed processed signal, the known component and an unwanted noise in the input signal; error signal means for obtaining an error signal from the filtered input signal; and means for controlling the adaption of the filtering characteristics in response to the reference signal and the error signal to provide that the filter adapt to cancel the known feedback component and to filter the unwanted noise in the input signal provided that the rapid adaption is actuated at a time when the unwanted noise is predominant in the input signal, whereby the filter is adapted to the characteristics of the feedback path and the prevailing noise conditions in the user's environment at a time controlled by the user.

In an alternative embodiment, the present invention provides, a method for cancelling the feedback component. An electrical input signal is produced from the auditory environment having the original input component and having the feedback component. The electrical input signal is processed to produce a processed signal. A receiver receives the processed signal and converts the processed signal into an acoustic output signal. The feedback component is cancelled from the electrical input signal using an adaptive filter having selectively adaptable filtering characteristics. The adaptive filter selectively adjusts the adaptable filtering characteristics based upon the electrical input signal and the processed signal in response to the user.

In an alternative embodiment, the present invention provides a method for cancelling feedback and filtering an unwanted noise in the input signal of an auditory prosthesis. An input filter is operated to cancel a feedback component from the input signal in accordance with a reference signal to provide a filtered input signal for amplification by the auditory prosthesis, the filter having adaptable characteristics. The filtered input filter is amplified to provide an processed signal. The reference signal is obtained from the processed signal and supplied to the input filter. The filtering characteristics are rapidly adapted at a time controlled by the user of the system. The rapid adaption introduces a predetermined signal into the output of the system so that the predetermined signal travels through a feedback path to the input of the auditory prosthesis to provide that the input signal contain a known feedback component corresponding to the predetermined signal; adds to the reference signal during the rapid adaption a signal containing a component corresponding to the predetermined

signal and a signal obtained from the input signal containing a component corresponding to the unwanted noise so that the reference signal contains components from the processed signal, the predetermined signal and the input signal during adaption of the filtering characteristics; obtains an error signal to be used in adapting the filtering characteristics, the error signal taken from the filtered input signal; and rapidly adapts the filtering characteristics in accordance with the reference signal and the error signal to provide that the filtering characteristics are adapted to cancel the known feedback component and filter unwanted noise from the input signal in accordance with the characteristics of the feedback path and the unwanted noise in the input signal at the time of adaption.

Brief Description of the Drawings

The foregoing advantages, construction and operation of the present invention will become more readily apparent from the following description and accompanying drawings in which:

Figure 1 is a perspective drawing of the auditory prosthesis of the present invention mounted in a housing "behind the ear" of the user;
Figure 2 is a block diagram of an auditory prosthesis constructed according to the present invention;
Figure 3 is a block diagram of an auditory prosthesis illustrating an alternative embodiment of the present invention;
Figure 4 is a block diagram showing an auditory prosthesis having an alternative feedback cancellation system of the present invention;
Figure 5 is a simplified block diagram of the operation of an adaptive filter that can be used in the auditory prosthesis of the present invention;
Figure 6 is a block diagram showing an auditory prosthesis including feedback cancellation and noise cancellation according to the present invention;
Figure 7 is a simplified block diagram of the method according to the present invention; and
Figure 8 shows alternative implementations of the present invention.

Detailed Description of the Preferred Embodiments

Referring to Figure 1, auditory prosthesis 10 is illustrated as being a "behind the ear" hearing aid mounted on the ear 12 of the user. Although the preferred auditory prosthesis 10 is a hearing aid mainly intended for hearing impaired persons, other types of auditory prostheses are also envisioned. An example would include an ear muff intended to be used by persons in high noise environments or other environments where a greater degree of intelligibility of speech is desired. Other types of hearing aids are also envisioned. Working similarly with the present invention would also be "in the ear" hearing aids and "in the canal" hearing aids. Auditory prosthesis 10 is mounted in housing 12. Microphone 16 is mounted in housing 12 in a position to receive auditory signals, e.g., sound, from the environment of the wearer of auditory prosthesis 10. Receiver 18 is mounted in housing 12 so that it projects amplified sound into the wearer's ear 12, preferably through ear piece 20. Switch 22, preferably a push button switch, is mounted on the outside of housing 12 to be accessible by the user. Switch 22 enables the user of auditory prosthesis 10 to have control over the ability of auditory prosthesis 10 to adapt to cancel feedback from the environment of the user of auditory prosthesis 10.

Figure 2 is a diagrammatic/block diagram of auditory prosthesis 10 operating in conjunction with the environment of the user's ear 12. Auditory prosthesis 10 receives auditory signals (sounds) from the environment of the user. Contained in the user's auditory environment is the acoustic input signal 24 containing the signal of interest, e.g., speech, and a feedback signal 26. Since these signals are nominally acoustic signals, they are represented by "wavy" lines. Feedback signal 26 originates from the acoustic output signal 28 which emanates from receiver 18, speaker in hearing aid parlance, of auditory prosthesis 10. Acoustic output signal 28 travels back into the environment of auditory prosthesis 10 through housing 14 (shown in Figure 1) of auditory prosthesis 10, the user's body tissue, through the air, or any combination thereof. During this process acoustic output signal 28 may be attenuated, distorted or otherwise disturbed from its original condition. This process is represented in Figure 2 as feedback path 30 having transfer function H_f.

Thus, both the desired acoustic input signal 24 and the undesired feedback signal 26 are present at microphone 16 and available to be processed by auditory prosthesis 10. Auditory prosthesis 10 contains signal processor 32 which is used conventionally to provide the desired modification to acoustic input signal 24. This modification is represented as transfer function H_s. For example, in a hearing aid embodiment, signal processor 32 would provide selective amplification in the frequencies necessary to compensate for the hearing impairment of the user. In another example, signal processor 32 would provide the desired signal processing to enable an increased amount of intelligibility to a user who is not hearing impaired. Signal processor 32 can be of the design shown in U.S. Patent No. 4,425,481, Mangold et al, Signal Processor, or U.S.

Patent No. 4,548,082, Engebretson et al, Hearing Aids, Signal Supplying Apparatus, Systems For Compensating Hearing Deficiencies, and Methods, or any other known design suitable for amplifying an input signal in a hearing aid application. Alternatively, signal processor 32 can be simply be an amplifier.

An input filter consisting of adaptive filter 34 and summing junction operates to cancel feedback in the auditory prosthesis. Adaptive filter 34 receives the output of signal processor 32 as an input. The output of adaptive filter 34 is provided to summing junction 36 where this output is subtracted from the electrical signal supplied by microphone 16. Adaptive filter 34 is also supplied with the electrical input signal to signal processor 32 which is used to adapt the filtering characteristics of adaptive filter 34. The connections of and the operation of adaptive filter 34, as discussed to this point, is conventional in the art. Adaptive filtering in feedback situations with auditory prostheses is well known and is described in Bustamante, Diane K., Worrall, Thomas L. and Williamson, Malcolm J., Measurement and Adaptive Suppression of Acoustic Feedback in Hearing Aids, *ICASSP 1989 Proceedings*, pp. 2017-2020, IEEE (1989), which is hereby incorporated by reference.

User operated control 38 is provided to control adaptive filter 34. In one preferred embodiment, user operated control 38 may be switch 22, preferably a push-button switch. Adaptive filter 34 can effectively adapt to cancel feedback signal 26 from the signal processing path of auditory prosthesis when feedback signal 26 predominates in the user's environment. That is, when feedback signal 26 is much larger than acoustic signal 24, or when acoustic signal 24 is not present in the environment, adaptive filter 34 may easily, according to known adaptive filtering methods and techniques, be adjusted to transfer function H_a in order to subtract out a signal substantially equal to feedback signal 26 at summing node 36. This effectively removes feedback signal 26 from the processing path of auditory prosthesis 10 and prevents the feedback signal 26 from being reproduced by receiver 18 and reaching the user's ear 12.

User operated control 38 is provided so that the user of auditory prosthesis 10 may implement the adaption of adaptive filter 34 only in certain circumstances or under certain conditions. Adaptive filter 34 is always operable in auditory prosthesis 10 to cancel feedback signal 26 from the signal processing path. However, it is not always desirable that adaptive filter be changing its filtering characteristics, i.e., adapting. When acoustic signal 24 predominates in the environment, adaption of adaptive filter 34 will tend the cancel the desired signal, i.e., acoustic signal 24. Thus, the user may utilize user operated control 38 to select the times or intervals during operation of auditory prosthesis 10 when adaptive filter will adapt. Generally, the user should select times or circumstances during which feedback signal 26 predominates over acoustic signal 24 in the environment.

Figure 3 illustrates an alternative embodiment of auditory prosthesis 10. Auditory prosthesis 10 of Figure 3 is identical to auditory prosthesis 10 of Figure 2 except for the addition of probe generator 40 and summing node 42. In periods of relative quiet, or in order to more effectively adapt to feedback signal 26 when there is little component of acoustic signal 24 in the environment, the user may utilize user operated control 38 to both cause adaptive filter 34 to adapt its filtering characteristics and to cause probe generator 40 to introduce a predetermined signal 44 to be summed with the output of signal processor 32 at summing node 42. This will introduce a predetermined component into acoustic output signal 28 which will then be fed back in feedback signal 26 to microphone 16. The presence of predetermined signal 44 in feedback signal 26 will, in the absence of acoustic signal 24 from the environment, aid adaptive filter 34 in adapting its filtering characteristics to cancel feedback component 26 from the environment. Preferably, probe generator 40 also supplies a predetermined signal 46 directly to adaptive filter 34 to aid in the adaption process.

Figure 4 illustrates an alternative embodiment of auditory prosthesis 10 according to the present invention. Auditory prosthesis 10 includes microphone 16, input filter 48 having an adaptive filter 58, signal processor 32, delay 50, summing node 52, receiver 18, probe generator 40, summing node 54, delay 56, and user operated control 60 shown controlled by user switch input 24a. Summing nodes 52 and 54 can have programmable gain so that the mix of the input signals can be controlled. In a preferred embodiment user operated control 60 controls the gain of summing node 52, summing node 42 and probe generator 40. Shown diagrammatically in Figure 4 is feedback path 30 and summing junction 62. Summing junction 62 diagrammatically illustrates the combining in the environment of feedback signal 26 and acoustic signal 24 of interest.

Both feedback signal 26 and acoustic signal 24 are applied to microphone 16. Microphone 16 generates a corresponding electrical input signal y(n) which is filtered by input filter 48 and then applied to signal processor 32. The output of signal processor 32 is delayed at delay 50, and then applied to summing node 52, the output of which is applied to receiver 18. Receiver 18 generates amplified sound 28 for the hearing aid user. The output of delay 50

is also applied to summing node 42, which in turn applies its output to delay 56. The output of delay 56, the signal d(n), is applied to the reference input of an adaptive filter 58 contained within input filter 48. As will be explained in more detail below, adaptive filter 58 provides an output signal x(n) in response to the reference input d(n). The output x-(n) is subtracted from the input signal of y(n), at summing node 64. When properly adapted, adaptive filter 58 provides that the feedback component of the signal y(n) is subtracted at summing node 64 so that the signal applied to signal processor 32 is substantially free from feedback, thus substantially preventing amplification of feedback.

Probe generator 40 is provided for the purpose of generating a predetermined signal 66, preferably a known broadband noise signal, for use in adapting filter 58. As will be described in more detail below, the noise signal output of probe generator 40 is applied to receiver 18 through summing node 52 to provide a known broadband sound at the output of receiver 18. A component of this noise travels through feedback path 30 to microphone 16, where it contributes a feedback component 26 to signal y(n). Probe generator 40 provides the same signal 68 to delay 56 through summing node 54. Delay 56 in turn provides the delayed signal d(n) to the reference input of adaptive filter 58. Adaptive filter 58 adapt its characteristics in response to the error signal e(n), which is taken from the output of summing node 64. Delay 50 is provided to decorrelate feedback signals in the feedback path from the acoustic signals arriving at the microphone 16, while delay 56 is provided to match the pure delay of the feedback path. This provides that the error signal e(n) applied to the error signal input of adaptive filter 58 is substantially proportional to the acoustic signal of interest plus any uncanceled feedback signal passing through summing node 64. The delay introduced by delay 50 is preferably on the order of several milliseconds and greater, while the delay from delay 56 is on the order of a millisecond or two, as adjusted to match the pure delay of feedback as it travels from the receiver and back into input signal.

Referring now to Figure 5, there is shown diagrammatically an example of an adaptive filter 70 suitable for use as filter 58 in the auditory prosthesis of Figure 4. Adaptive filter 70 receives input data d(n) 72. The input data din) may be preprocessed in block 74. Following preprocessing, if any, the Adaptive filter 70 includes a plurality of taps 1, 2, 3...N, and a plurality of corresponding tap coefficients C(1), C(2), C(3)...C(N). In operation, the taps hold a vector of data U(n) = [u(n), u(n-1), u(n-2)...u(n-N+1)] at a time n. Data vector U(n) is obtained from the reference signal input d(n). Each tap coefficient C(N) corresponds to an element of a tap coefficient vector $H_a(n)$ = [$h_a(n,l)$, $h_a(n,2)$, $h_a(n,3)$...$h_a(n,N)$]. Filter 58 includes means for multiplying the corresponding elements in data vector U(n) and coefficient vector $H_a(n)$ to provide a corresponding product vector P(N) = [P(1), P(2), P(3)-...P(N)]. This product vector is summed at a time n to provide the filter output signal x(n) wherein x(n) = $[H_a(n)]$ t U(n) wherein t equals the vector transpose. Adaptive filter 70 is thus operative at any given time n to provide an output signal x(n) which is a function of reference signal d(n) and the tap coefficient vector $H_a(n)$.

When filter 58 is adapting, as will be explained in more detail below, the H_a coefficient vector is updated to minimize the error signal e(n) arriving at its error signal input of the filter. The coefficient vector is updated to minimize the expected value of the squared difference between y(n), the acoustical signal plus feedback at time n and x(n), the output of the adaptive filter 58, i. e., $e(n)^2$ wherein e(n) = y(n)-x(n). Using least-means-square (LMS) adaption on the updated coefficient vector at a time n + 1, $H_a(n + 1)$ is computed by $H_a(n + 1)$ = h-(n) + μ x e(n) x U(n), wherein μ is an adaption parameter which controls the rate of adaption in the filter. Using polarity or sign-sign adaption it is computed by: H_a (n + 1) = ($H_a(n)$ + u x [sign[e(n) x U(n)]}. In the equations, "x" represents a multiplication operation.

Auditory prosthesis 10 is operative in any one of three basic modes to provide adaption of filter 58 to meet feedback cancellation requirements. In one mode of operation, adaption is user activated via user operated control 60, and is done rapidly. During rapid adaption immediately following switch activation by the user, probe generator 40 is turned on by user operated control 60 and the gain of summing node 52 is set by user operated control 60 to mix the known feedback signal into the output of the amplifier. The contribution from the output delay 50 remaining constant. The net affect is set to provide a high level of probe noise to allow accurate identification of the frequency response of the feedback path. A known feedback signal strength about 40 dB below the maximum output of the auditory prosthesis has been found suitable. Simultaneously, the adaption control parameter μ of adaptive filter 58 set by user operated control 60 to a relatively large value to provide fast convergence and adaption to stop oscillatory feedback if it is already occurring. Once the filter is nearly converged, μ is reduced to a smaller value so that adaption proceeds at a slower rate to produce an accurate convergence. This rapid adaption interval preferably is designed to take approximately one second or less. Two-step adaption as described is preferred because if μ remains large the filter continues to adapt once it is nearly converged

and the adaption process itself adds unwanted noise and distortion to the signal. A smaller μ value at the latter stage of adaption permits more accurate convergence and reduces unwanted adaption noise and distortion. Although it is contemplated that a two-step adaption process will suffice to provide rapid yet accurate convergence, more than two steps can also be used if desired or required, and accordingly the invention is in no way limited to a two-step process. Multiple-step adaption is especially important when the sign-sign algorithm is used, because adaption rate and adaption noise depend entirely on the magnitude of μ, while with LMS the magnitude of e(n) also influences adaption rate and adaption noise. In any event, once the rapid adaption interval is complete, the known feedback signal applied to receiver 18 is either turned off or set to a very low level, in accordance with which of the other modes of operation the auditory prosthesis is set to operate in, as will be explained below.

The auditory prosthesis 10 can also be set by user operated control 60 to operate in a slow adaption mode wherein filter 58 continuously adapts to adjust to changes in the characteristics of feedback, or may be set with the filter coefficients fixed, or frozen, until such time either the rapid or slow adaption mode is reinitiated. In the slow adaption mode, the adaption parameter μ of filter 58 is set a relatively small value and the gain of summing node 52 is adjusted to provide a very low probe feedback signal for application to receiver 18. Preferably, but without limitation thereto, rapid adaption is approximately 32 times faster than the rate of slow adaption. Ideally, the known feedback signal is adjusted so that it is inaudible to the hearing aid user but high enough to provide enough signal to excite the feedback path sufficiently for the adaptive filter to remain converged. Generally, a known feedback signal strength about 60 dB down from maximum auditory prosthesis output has been found suitable for this purpose. However, if the feedback signal cannot be reduced far enough to make it inaudible, for example in the case of hearing aid user with near normal sensitivity to some frequencies, it can be turned off altogether during slow adaption. With the feedback signal off, the broadband signal required for convergence is obtained from speech or other suitable environmental sounds. However, during intervals when no speech or other broadband signal is present at the microphone, filter 58 will diverge. Accordingly, in the case where slow adaption is provided but the probe generator 40 is turned off, user operated control 60 preferably includes circuitry for monitoring the signal level in one or more of the hearing aid channels to detect the absence of broadband input above a specified threshold. During such intervals, the user operated control 60 activates the probe 18 and summing node 52 automatically to provide a low level known feedback signal for a brief, fixed interval long enough to allow the filter to reconverge and is then turned off again.

During slow adaption operation, auditory prosthesis 10 operates normally to amplify acoustic sounds in the environment for the hearing aid user. Accordingly, since slow adaption operation permits the adaptive filter 58 to continuously track the small, slow changes in the feedback path that eventually will produce filter mismatch and feedback leakage if the coefficients are frozen, it is contemplated that operating the auditory prosthesis in a slow mode on a continuous basis between user-actuated rapid adaption intervals is preferred. Thus configured, the auditory prosthesis according to the present invention keeps to a minimum the number of times that user actuated rapid adaption is necessary and correspondingly keeps to a minimum the intervals of time in which the hearing of the user is interrupted to accomplish rapid adaption.

Thus, as described above, the present invention provides an auditory prosthesis 10 for canceling feedback wherein when operated in the slow adaption mode it can track and compensate for gradual changes in the feedback path, and wherein the user can activate rapid adaption so that the auditory prosthesis can quickly make substantial readjustments in its feedback cancellation characteristics as may be required where sound conditions in the user's environment change quickly or when the fitting of the hearing aid is disturbed, thus changing the characteristics of feedback path 30. The auditory prosthesis is advantageous to the auditory prosthesis disclosed in Graupe et al '818 in that it does not require special circuitry for detecting changes in the feedback response of the auditory prosthesis, and moreover is advantageous because it permits gradual tracking and updating the feedback cancellation characteristic of the auditory prosthesis without interrupting the listening of the user. Moreover, the user has complete control over when to actuate rapid adaption so that there is no possibility that uncontrolled feedback will go undetected and uncorrected as might occur in the auditory prosthesis disclosed in Graupe et al '818.

<u>Feedback Cancellation with Background Noise Filtering</u>

Referring now to Figure 6, there is shown an embodiment of the invention in an auditory prosthesis 80 wherein both feedback cancellation and background noise filtering capabilities are provided. As explained above, environmental noise is a sub-

stantial problem for a user of a hearing aid wherein the noise is amplified to the extent it interferes with the user's ability to hear the signal of interest, which is typically speech. Generally, the type of background noise most problematic to users of a hearing aid is "constant background noise", which can be defined as relatively long duration noises having near stationary spectral characteristics such as the noises associated with passing cars, trains and airplanes or running fans or machinery. This environmental noise, if not filtered from the input of the hearing aid system often not only interferes with the user's ability to understand the signal of interest, but is disturbing and sometimes even physically painful for the user. The noise filtering auditory prosthesis disclosed in said co-pending application includes, generally, a user-actuated adaptive input filter which when actuated rapidly adapts its filtering characteristics to match the prevailing noise conditions in the environment. The auditory prosthesis uses the input signal from the microphone as the reference input to the adaptive filter and is actuated during intervals in which substantially only unwanted constant background noise is present in the environment, as determined by the user. The filter thus rapidly adapts to eliminate the unwanted constant background noise component of the input signal. That auditory prosthesis further includes a slow adaption mode of operation wherein gradual changes in the characteristics of constant background noise may be adjusted for.

Auditory prosthesis 80 of the present invention provides for both feedback cancellation and the filtering of unwanted constant background noise from the input signal of the hearing aid system. As shown in Figure 6, auditory prosthesis 80 is of generally the same construction as auditory prosthesis 10 as shown in Figure 4. Accordingly, the components of auditory prosthesis 80 which correspond to those of the components of auditory prosthesis 10 are given the same reference numerals as those in Figure 4 except for "prime" designations. Auditory prosthesis 80 includes, however, in addition to the components of the auditory prosthesis of Figure 4, a summing node 82 and a delay 84. Delay 84 delays the input signal y(n) and provides the delayed input signal y'(n) to summing node 82. Summing node 82 adds the delayed signal y'(n) to the d(n) signal and applies the summed signals to the reference signal input of adaptive filter 58'. Delay 84 serves to decorrelate y'(n), which provides the constant background noise reference signal to filter 58', from the primary signal y(n).

Auditory prosthesis 80 has the same three basic modes of operation as auditory prosthesis 10, i.e., a user-actuated rapid adaption mode, a continuous slow adaption mode, and a fixed, no adaption, mode. Thus, it operates in exactly the same manner as auditory prosthesis 10 but for the additional background noise filtering and adaption capability, as explained more fully below. As thus configured, auditory prosthesis 80 operates the same as auditory prosthesis 10 with respect to the cancellation of feedback, but is also operative to filter unwanted constant background noise from the input signal as well. More specifically, during adaption, adaptive filter 58' is responsive not only to the d(n) signal presented by delay 56', but also to the y'(n) reference signal in order to adjust its filtering characteristics. As in the auditory prosthesis of said co-pending application, during those time intervals when the background noise reference signal y'(n) predominates, at least on average, the reference signal y'(n) component of the total reference signal causes filter 58, to adjust to filter this component of the input signal y(n). Accordingly, the auditory prosthesis is preferably activated for rapid adaption at only such times that constant background noise predominates in the user's environment. The filter 58' thus adapts to provide that its characteristics are adjusted to not only cancel feedback, but also to filter unwanted constant background noise from the primary y(n) signal input. Moreover, when operative in a slow adaption mode, the y'(n) noise reference signal input component causes adaptive filter 58, to hunt towards the characteristic which will filter unwanted constant background noise from the input. The decorrelation of y'(n) from y(n) via delay 84 provides that adaptive filter 58' is inhibited from adjusting its filtering characteristics to filter out desired signal of interest, and moreover the slow rate of adaption provides that the overall net adjustment of filter 58' hunts toward the desired setting inasmuch as the unwanted constant background noise is most often present at the input of microphone 16', for time durations longer the signal of interest, which is typically speech.

Auditory prosthesis 80 of the present invention thus provides an auditory prosthesis which utilizes the intelligence of the user of the hearing aid to select and control the filter adaption process both for adjustment to changes in unwanted constant background noise and/or feedback conditions. The auditory prosthesis of the present invention is more desirable than the auditory prosthesis disclosed in Graupe et al '721 for filtering background noise because the hearing aid user enjoys control over the filtering characteristics of the hearing aid, and because filtering characteristics are changed in direct response to the user's needs and desires as opposed to preprogrammed unalterable criteria set in the hearing aid design. In particular, the auditory prosthesis of the present invention provides that the user can define the "unwanted" background noise sought to be eliminated by activating rapid

adaption while the unwanted noise is predominant in the input signal. In addition, the continuous adaption mode provides the advantageous characteristics of the auditory prosthesis disclosed in Graupe et al '721 to continually adapt to changing environmental background noise while at the same time eliminating the annoying "pumping" noise generated by the auditory prosthesis disclosed in Graupe et al '721 wherein abrupt changes in filtering characteristics audible to the user are made continuously. Moreover, the auditory prosthesis of the present invention is simpler in design and consequently less costly than the auditory prosthesis disclosed in Graupe et al '721 because it does not require circuitry to detect the presence and absence of speech in the user's environment, circuitry necessary to the operation of the auditory prosthesis disclosed in Graupe et al '721.

Referring to Figure 7, the method of both the auditory prosthesis 10 and 50 is shown in simplified block diagram flow chart form. As generally shown in Figure 7, the method begins with step 90 in which the filter is initiated to an initial filtering configuration, for instance upon turn on of the auditory prosthesis. The filter can be set so that the characteristics are fixed or so that the filter slowly adapts on a continuous basis (92). Block 94 represents the operation of filter 58 or 58' to filter the input signal, either with fixed characteristics or with slowly changing characteristics if the filter is set to slowly adapt. The filter continues to operate in this manner unless and until the user actuates filter 58 or 58' to rapidly adapt, as represented by block 96. In the case of auditory prosthesis 10, the user activates rapid adaption when feedback effects become noticeable and/or irritating, to cause rapid adjustment to eliminate feedback amplification. In the case of auditory prosthesis 80, the user actuates the auditory prosthesis to rapidly adapt either in response to changed feedback conditions or to change the auditory prosthesis's noise filtering characteristics. In either case, the user preferably actuates rapid adaption only when unwanted background noise predominates in the environment, so that the filter adjusts to obtain the most optimum characteristics for the purpose of filtering unwanted noise. As also noted in block 94, a multiple-step rapid adaption process is used. Once rapid adaption is complete, the filter is set back either to operating with fixed characteristics or to slowly adapt (92), and returns to normal filtering operation (94). If the filter 58 or 58' is set to slowly adapt while filtering in its normal mode of operation, the adaption is paced such that no abrupt changes in filtering response are discernible by the user, thus avoiding the "pumping" sounds so annoying to user's of the above noted auditory prosthesis disclosed in Graupe et al '721, but yet allowing the filter 58 or 58' to gradually adjust to prevailing feedback and noise conditions. During slow adaption, the method thus calls for the probe generator 40 to either be set to a low inaudible level or off. If set off, the method calls for reactivating it at a low level if no environmental broadband signal is present to prevent filter divergence.

Filter Alternatives

While a specific filter embodiment has been described, it shall be understood that the invention is in no way limited in this respect. Either analog or digital filtering circuits such as minimum variance time domain filter, an augmented Kalman noise filter, or a Wiener filter can be used for filters 58 and 58'. Alternatively, the filter can be an adjustable notch filter. Samples of such filters are described in the following references: Sage and Melsa, Estimation Theory with Applications to Communications and Control, McGraw Hill (1971); N. Levenson and N. Wiener, Extrapolation, Interpolation and Smoothing of Stationary Time Series, MIT Press (1964); Y. Z. Tsypkin, Foundations of the Theory of Learning System, Academic Press, N. Y. (1973); M. Schwarz and L. Shaw, Signal Processing, McGraw Hill, N. Y. (1975); and D. E. Johnson and J. L. Hillburn, Rapid Practical Design of Active Filters, John Wiley & Sons, N. Y. (1975). Examples of suitable digital filters are found in the publication: D. Graupe, Time Series Analysis, Identification and Adaptive Filtering, pp. 20- 100, Krieger Publishing Co., Malabar, FL. (1984).

Other Alternate Embodiments

The present invention, while particularly useful in its application to the hearing aid arts, finds application more generally in auditory prostheses at large. Referring to Figure 8, there is shown the adaptive filter of the present invention as used in other applications as generally denoted as an auditory prosthesis 100. A source of input signal 102 provides the input signal to filter 58 or 58' which is sought to be filtered to eliminate an unwanted component or feedback. Input signal source 102 may be, for instance, the microphone of a public address auditory prosthesis or of an equipment operator's headset, for example the headset of a fighter pilot or tank operator. In such cases the background noise sought to be eliminated is the noise from the equipment being operated, for instance the noise present in the cockpit of a jet or inside a tank, with respect to the examples above noted. The feedback path would be from the loud speaker of the public address auditory prosthesis to the auditory prosthesis's microphone or from the receiver of a headset to the headset's microphone.

In such cases, the filter 58 or 58' can be used to filter out the noise from the equipment from the speech component of the microphone input and cancel any feedback thus enhancing the clarity of the amplification/communication. Block 104 generally represents the amplification and receiver/loudspeaker components of auditory prosthesis 100.

The above-noted applications of filter 10 are not intended to be limiting in any respect but merely illustrative of the broad range of potential signal filtering applications to which filter 58 or 58', can be put. In this regard it is noted that filter 58 or 58', can be applied anywhere in a signal processing stream and is in no way limited to application near the source of input signal. For instance, it could be implemented downstream of other signal processing circuits.

Although the invention has been described above in its preferred form, those of skill in the art will recognize that various changes and modifications may be made thereto without departing from the spirit and scope of the invention as set forth in the claims that follow.

Claims

1. An auditory prosthesis adapted to be used by person in an auditory environment having an original input component and having a feedback component originating from said auditory prosthesis, comprising:

   an input transducer for producing an electrical input signal from said auditory environment having said original input component and having said feedback component;

   a signal processor for processing said electrical input signal to produce a processed signal;

   a receiver receiving said processed signal and converting said processed signal into an acoustic output signal;

   an input filter operatively coupled to said signal processor for cancelling said feedback component from said electrical input signal, said input filter having selectively adaptable filtering characteristics; and

   user controlled means coupled to input filter for selectively causing said input filter to adjust said adaptable filtering characteristics based upon said electrical input signal and said processed signal in response to said user.

2. An auditory prosthesis adapted to be used by person in an auditory environment having an original input component and a feedback component originating from said auditory prosthesis, comprising:

   an input transducer for producing an electrical input signal from said auditory environment having said original input component and having said feedback component;

   a signal processor for processing said electrical input signal to produce a processed signal;

   a receiver receiving said processed signal and converting said processed signal into an acoustic output signal;

   an input filter coupled to said signal processor for cancelling said feedback component from said electrical input signal, said input filter having selectively adaptable filtering characteristics;

   probe means coupled between said signal processor and said receiver and coupled to said input filter for selectively generating a predetermined noise signal; and

   a user controlled means coupled to input filter and said probe means for selectively causing said probe means to generate said predetermined noise signal and for causing said input filter to adjust said adaptable filtering characteristics based upon said electrical input signal and said processed signal in response to said user.

3. An auditory prosthesis adapted to be used by person in an auditory environment having an original input component and a feedback component originating from said auditory prosthesis, comprising:

   an input transducer for producing an electrical input signal from said auditory environment having said original input component and said feedback component;

   an input filter for cancelling said feedback component from said electrical input signal to provide a filtered input signal, said input filter operative to cancel said feedback component in accordance with a reference signal, said input filter having selectively adaptable filtering characteristics;

   a signal processor for processing said filtered input signal to produce a processed signal;

   a delay for delaying said processed signal to produce a delayed processed signal;

   a receiver receiving said processed signal and converting said delayed processed signal into an acoustic output signal;

   reference signal means for obtaining said delayed processed signal and using it to produce said reference signal; and

   a user controlled means coupled to input filter for selectively causing said input filter to adjust said adaptable filtering characteristics

based upon said electrical input signal and said reference signal in response to manual activation by said user.

4. An auditory prosthesis according to claim 3 wherein said delay delays said processed signal sufficiently so as to decorrelate feedback in said processed signal from new signals arriving at said input transducer.

5. An auditory prosthesis according to claims 3 or 4, wherein said reference signal means includes means for delaying said reference signal a period of time substantially equal to the delay of said feedback path.

6. An auditory prosthesis according to claim 3, 4 or 5, wherein said feedback component of said auditory environment reaches said transducer along a feedback path, said feedback path having an inherent delay, and wherein said reference signal means includes means for delaying said delayed processed signal a period of time substantially equal to said delay of said feedback path to produce said reference signal.

7. An auditory prosthesis according to any one of claims 1 to 6, wherein said input filter includes means for rapidly adapting said filtering characteristics at a first rate to provide for fast convergence until said filtering characteristics are nearly converged and then at one or more progressively slower rates to provide more accurate convergence until said filtering characteristics are converged.

8. An auditory prosthesis according to claim 7 further wherein said adaption rate is controlled by an adaption rate parameter μ which is set to a first magnitude by said means for controlling to provide said first rate of adaption and then is progressively reduced one or more times by said means for controlling to provide said one or more slower rates of adaption, respectively.

9. An auditory prosthesis according to claim 8 wherein said rate of rapid adaption is approximately thirty-two times faster than said rate of slow adaption.

10. An auditory prosthesis adapted to be used by person in an auditory environment having an original input component and having feedback component originating from said auditory prosthesis along a feedback path, comprising:

an input transducer for producing an electrical input signal from said auditory environment having said original input component and having said feedback component;

an input filter having a reference signal input, said input filter receiving said electrical input signal and cancelling a selected feedback signal component from said electrical input signal in accordance with a feedback reference signal applied to its reference signal input to produce a filtered input signal;

a signal processor for processing said filtered input signal to produce a processed signal;

a first delay receiving said processed signal and producing a delayed processed signal;

a probe generator for generating a predetermined signal;

a first summing junction having two inputs and receiving at one of its inputs said delayed processed signal and said predetermined signal at its other input to produce an output signal comprising a mix of said signals;

a receiver operatively coupled to said output signal of said first summing junction for producing an acoustic output signal corresponding to said output signal;

a second summing junction having two inputs and receiving at one of its inputs said predetermined signal and receiving said delayed processed signal at its other input to produce a mix of said predetermined signal and said delayed processed signal at its output;

a second delay receiving the output of said second summing junction and producing said feedback reference signal; and

user controlled means for selectively generating a manually actuated signal in response to said user; and

said input filter having an adaptive filter for controlling the adaption of said filtering characteristics of said input filter, said adaptive filter including an input for said user manually actuated signal, said adaptive filter being responsive to said manually actuated signal for (i) causing said first summing junction to mix said predetermined signal into said output signal so that said electrical input signal contains said feedback component corresponding at least partially to said perdetermined signal as introduced via the feedback path between said output transducer and said microphone, (ii) causing said second summing junction to mix said predetermined signal into its output so that said reference signal contains a delayed component thereof, and (iii) causing said filtering characteristics of said input filter to rapidly adapt in accordance with the feedback compo-

nent in said electrical input signal, said feedback reference signal and an error signal taken from said filtered input signal so that said filtering characteristics are adapted to the characteristics of said feedback path whereby said input filter is operative to cancel feedback in said input signal.

11. An auditory prosthesis according to claim 10 further wherein said adaptive filter further includes means for slowly adapting the filtering characteristics of said filter during an interval of time when said filtering characteristics are not being rapidly adapted, said means for slowly adapting causing said first summing junction to prevent said unknown signal from being mixed in said output signal and instead using a broadband signal component present in the environment and in said input signal for the purpose of converging said filtering characteristics during adaption and causing said filtering characteristics to adapt at a slow rate relative to said rate of rapid adaption so that said filtering characteristics adapt to gradual changes in the characteristics of said feedback path and said unwanted noise.

12. An auditory prosthesis according to claim 11 further wherein said adaptive filter further includes means for slowly adapting the filtering characteristics of said filter during an interval of time when said filtering characteristics are not being rapidly adapted, said means for slowly adapting operative in a first mode for causing said first summing junction to prevent said predetermined signal from being mixed in said output signal and instead using a broadband signal component present in the environment and in said input signal for the purpose of converging said filtering characteristics during adaption and causing said filtering characteristics to adapt at a slow rate relative to said rate of rapid adaption so that said filtering characteristics adapt to gradual changes in the characteristics of said feedback path, and wherein said adaptive filter further includes means for detecting the absence of said broadband signal in said input signal and temporarily causing said first summing junction to add said predetermined signal to said output signal for a period of time sufficient to adapt said filtering characteristics to convergence.

13. An auditory prosthesis adapted to filter out an unwanted noise component and adapted to be used by person in an auditory environment having an original input component and having feedback component originating from said auditory prosthesis along a feedback path, comprising:

an microphone for producing an electrical input signal;

an input filter for cancelling a feedback component and an unwanted noise from said electrical input signal to provide a filtered input signal, said input filter being operative to cancel said feedback component in accordance with a reference signal and having selectively adaptable filtering characteristics;

a signal processor for processing said filtered input signal to produce an processed signal;

a delay for delaying said processed signal to produce a delayed processed signal;

an output transducer connected to said delay to produce an acoustic output signal corresponding to said delayed processed signal;

reference signal means for obtaining said delayed processed signal and using it to provide said reference signal;

said input filter having an adaptive filter for rapidly adapting the filtering characteristics of said input filter in response to a signal manually actuated by a user of said auditory prosthesis;

a probe generator operative during the time of rapid adaption for adding a predetermined signal to said delayed processed signal to cause said output transducer to produce an acoustic output signal having a predetermined component so that said predetermined component travels along said feedback path to said microphone to provide that said electrical input signal contains feedback component;

means for obtaining from said probe generator a feedback reference signal corresponding to said predetermined component and an unwanted noise reference signal from said input signal and adding them to said reference signal whereby said reference signal contains components corresponding to said delayed processed signal, said known component and said unwanted noise component in said electrical input signal;

error signal means for obtaining an error signal from said filtered input signal; and

means for controlling the adaption of said filtering characteristics in response to said reference signal and said error signal to provide that said filter adapt to cancel said feedback component and to filter said unwanted noise component in said electrical input signal provided that said rapid adaption is actuated at a time when said unwanted noise component is predominant in said electrical input signal;

whereby said input filter is adapted to the characteristics of said feedback path and said unwanted noise component at a time controlled by the user.

14. An auditory prosthesis according to claim 13 wherein said delay delays said processed signal sufficiently so as to decorrelate feedback in said processed signal from new signals arriving at said microphone.

15. An auditory prosthesis according to claim 13 or 14 further wherein said reference signal means includes means for delaying said reference signal a period of time substantially equal to the delay of said feedback path.

16. An auditory prosthesis according to any one of claims 10 to 15, wherein said adaptive filter includes means for rapidly adapting said filtering characteristics at a first rate to provide for fast convergence until said filtering characteristics are nearly converged and then at one or more progressively slower rates to provide more accurate convergence until said filtering characteristics are converged.

17. An auditory prosthesis according to claim 16 further wherein said adaption rate is controlled by an adaption rate parameter μ which is set to a first magnitude by said means for controlling to provide said first rate of adaption and then is progressively reduced one or more times by said means for controlling to provide said one or more slower rates of adaption, respectively.

18. In an auditory prosthesis adapted to be used by person in an auditory environment having an original input component and having a feedback component originating from said auditory prosthesis, a method for cancelling said feedback component, comprising the steps of:

producing an electrical input signal from said auditory environment having said original input component and having said feedback component;

processing said electrical input signal to produce a processed signal;

receiving said processed signal and converting said processed signal into an acoustic output signal;

cancelling said feedback component from said electrical input signal using an adaptive filter having selectively adaptable filtering characteristics; and

selectively causing said adaptive filter to adjust said adaptable filtering characteristics based upon said electrical input signal and said processed signal in response to said user.

19. A method as in claim 18 wherein said filtering characteristics are rapidly adapted at a time controlled by the user of said system, the rapid adaption comprising the steps of:

introducing a predeitermined signal into the output of said system so that said predetermined signal travels through a feedback path to the input of said auditory prosthesis to provide that said input signal contain a known feedback component corresponding to said predetermined signal;

adding to said reference signal during said rapid adaption a signal containing a component corresponding to said predetermined signal so that said reference signal contains components from said processed signal and said predetermined signal during adaption of said filtering characteristics;

obtaining an error signal to be used in adapting said filtering characteristics, said error signal taken from said filtered input signal; and

rapidly adapting said filtering characteristics in accordance with said reference signal and said error signal to provide that said filtering characteristics are adapted to cancel said known feedback component from said input signal in accordance with the characteristics of the feedback path at the time of adaption.

20. A method for cancelling feedback and filtering an unwanted noise in the input signal of an auditory prosthesis, comprising the steps of:

providing an input filter and operating said filter to cancel a feedback component from said input signal in accordance with a reference signal to provide a filtered input signal for amplification by said auditory prosthesis, said filter having adaptable characteristics;

processing the filtered input filter to provide a processed signal;

obtaining said reference signal from the processed signal and supplying it to said input filter;

rapidly adapting said filtering characteristics at a time controlled by the user of said system, the rapid adaption comprising the steps of:

introducing a predetermined signal into the output of said system so that said predetermined signal travels through a feedback path to the input of said auditory prosthesis to provide that said input signal contain a known feedback component corresponding to said predetermined signal;

adding to said reference signal during said

rapid adaption a signal containing a component corresponding to said predetermined signal and a signal obtained from said input signal containing a component corresponding to said unwanted noise so that said reference signal contains components from said processed signal, said predetermined signal and said input signal during adaption of said filtering characteristics;

obtaining an error signal to be used in adapting said filtering characteristics, said error signal taken from said filtered input signal; and

rapidly adapting said filtering characteristics in accordance with said reference signal and said error signal to provide that said filtering characteristics are adapted to cancel said known feedback component and filter unwanted noise from said input signal in accordance with the characteristics of the feedback path and the unwanted noise in said input signal at the time of adaption.

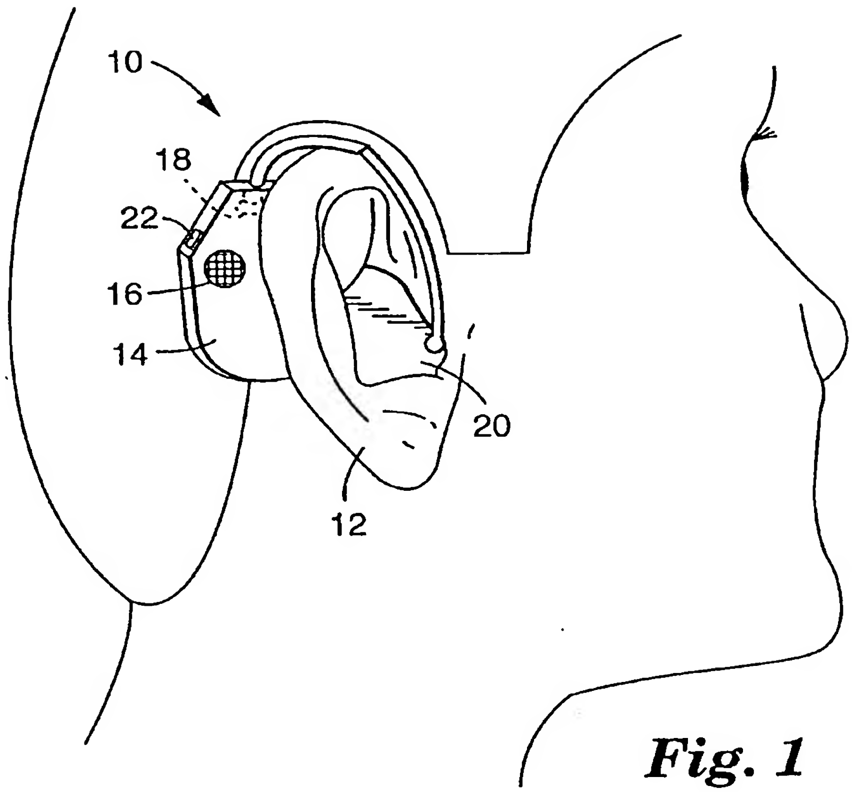

10
18
22
16
14
20
12

Fig. 1

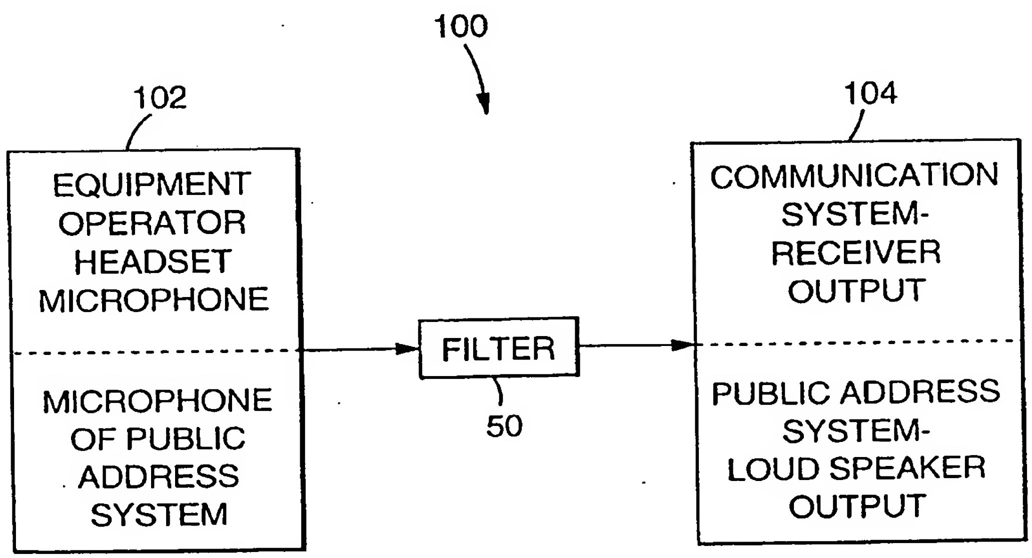
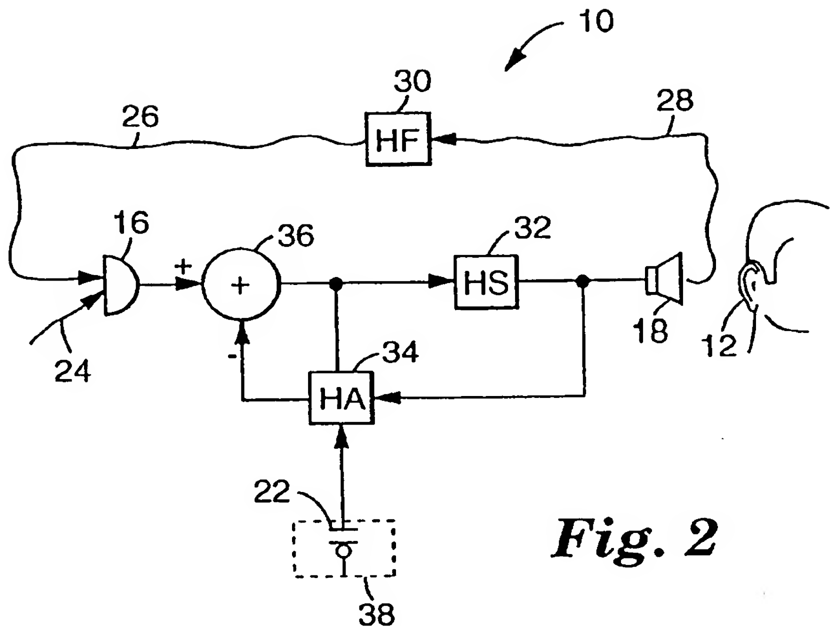

100
102
104
EQUIPMENT OPERATOR HEADSET MICROPHONE
MICROPHONE OF PUBLIC ADDRESS SYSTEM
FILTER
50
COMMUNICATION SYSTEM-RECEIVER OUTPUT
PUBLIC ADDRESS SYSTEM-LOUD SPEAKER OUTPUT

Fig. 8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30
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16
36
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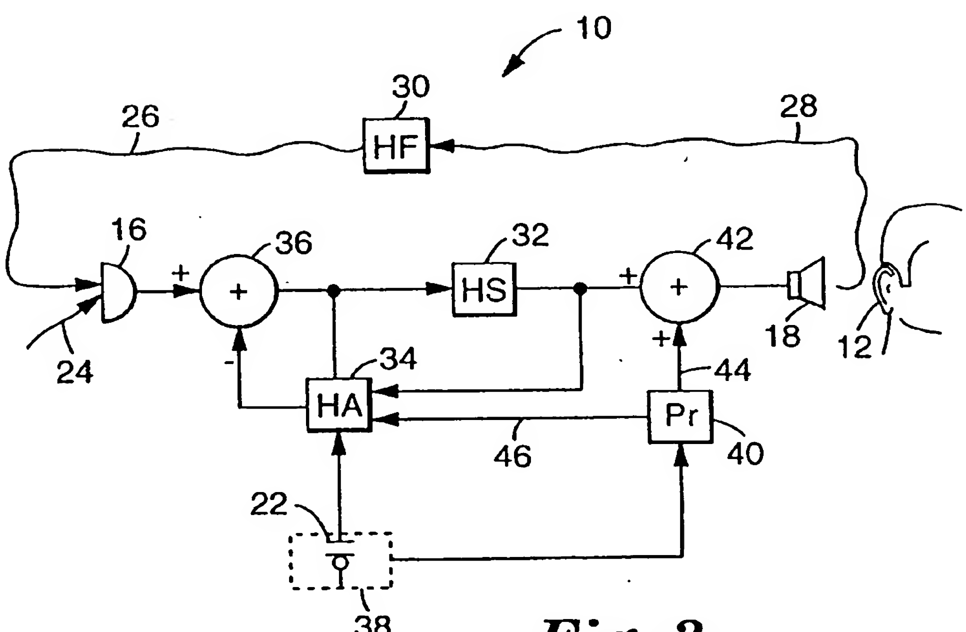
+
+
HS
18
12
24
-
34
HA
22
38

Fig. 2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36
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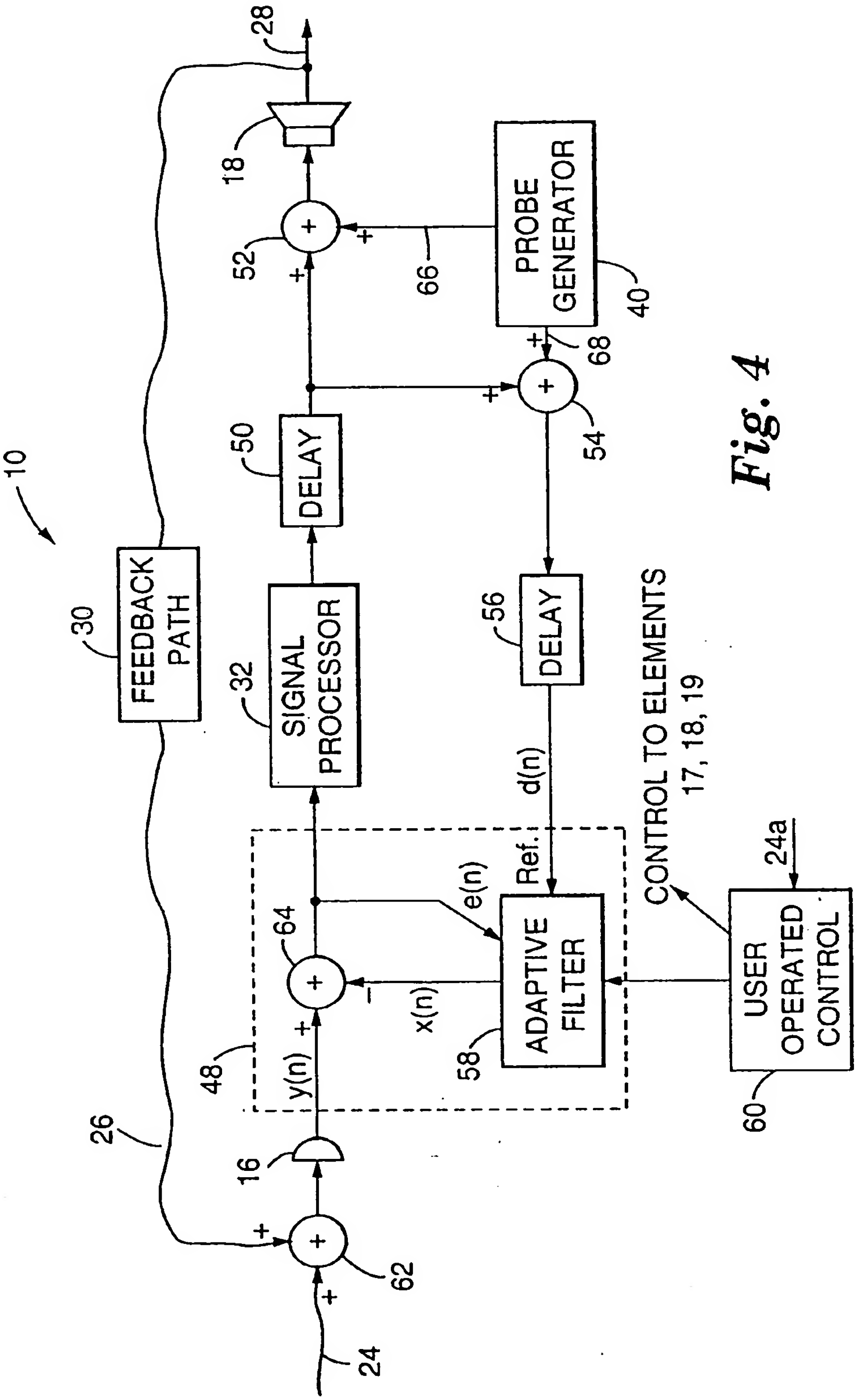
22
38

Fig. 3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28
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SIGNAL PROCESSOR
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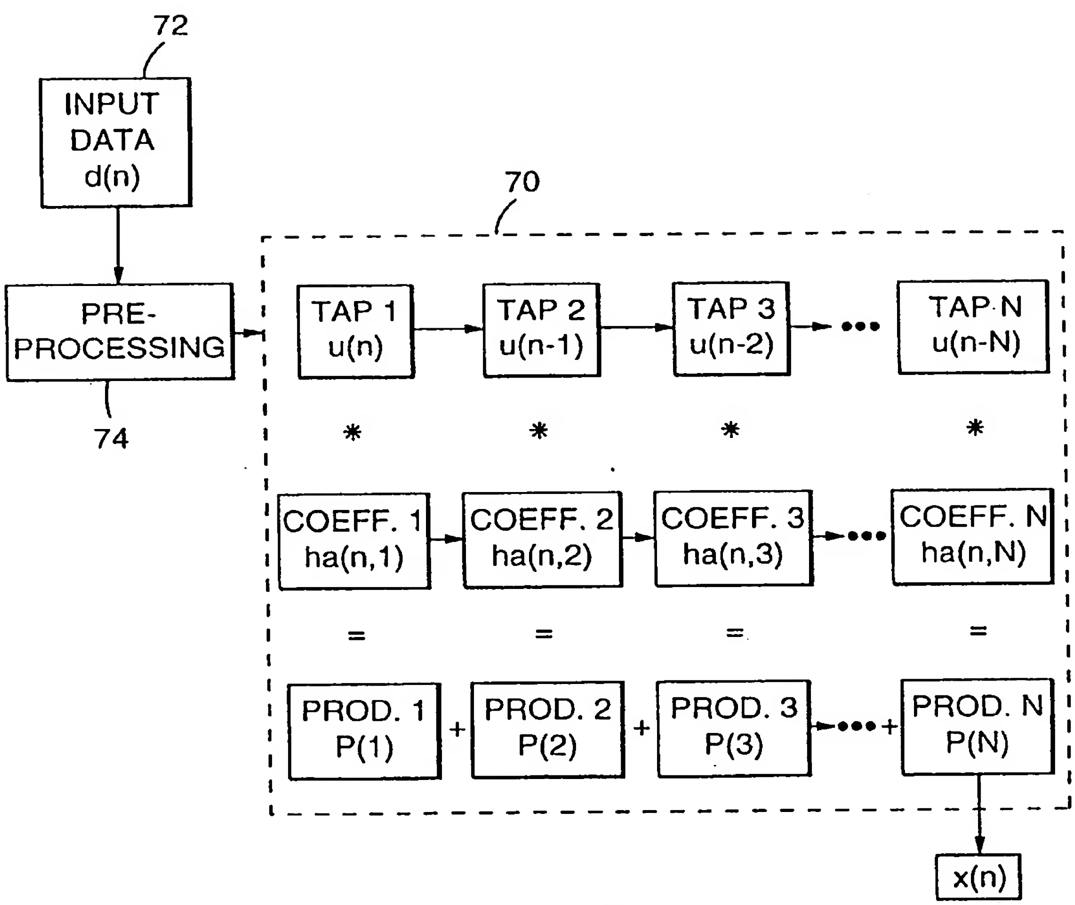
DELAY
50
52
66
PROBE GENERATOR
40
68
54
DELAY
56
d(n)
Ref.
e(n)
64
x(n)
y(n)
48
ADAPTIVE FILTER
58
16
62
24
CONTROL TO ELEMENTS 17, 18, 19
24a
USER OPERATED CONTROL
60

Fig. 4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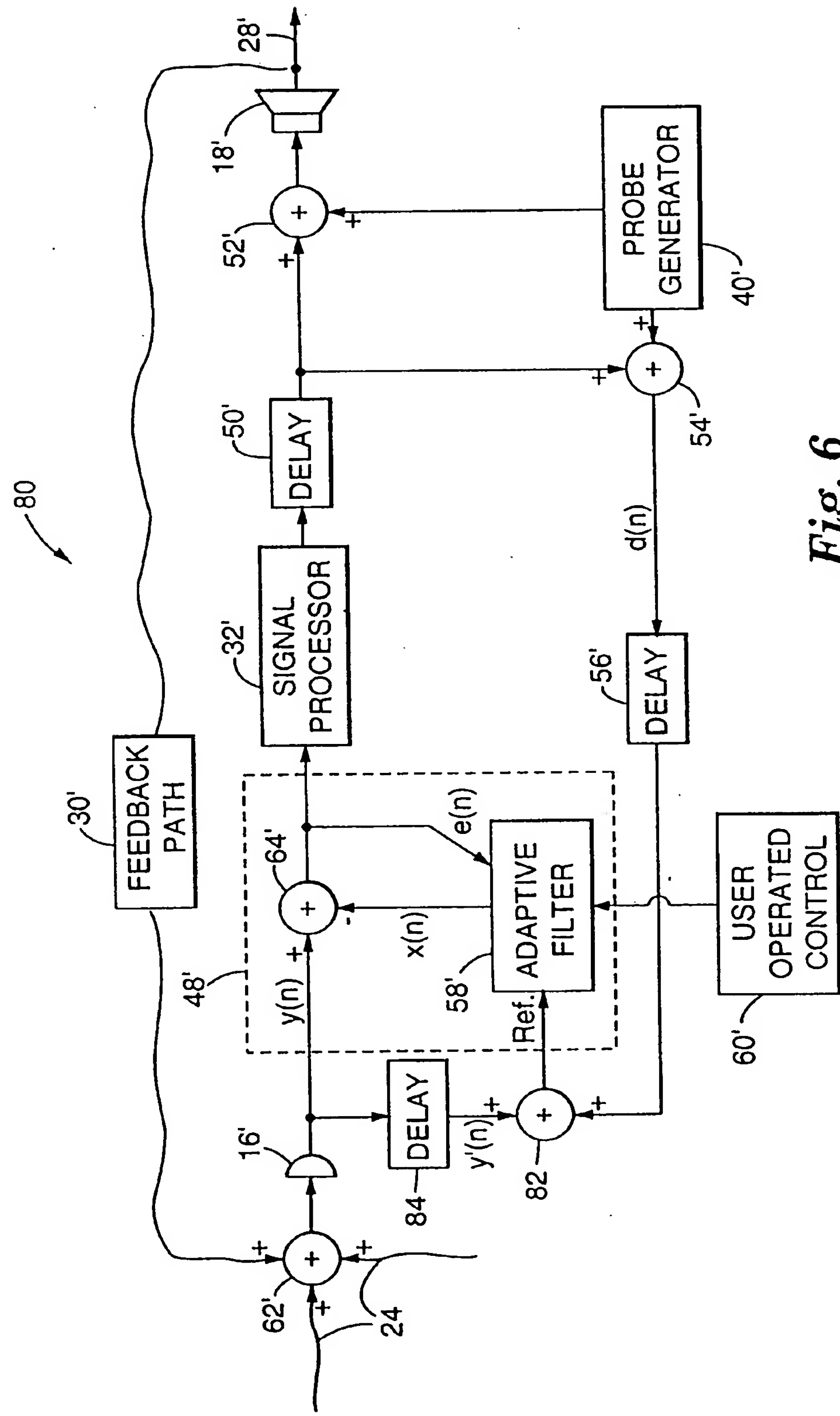
INPUT
DATA
d(n)
PRE-
PROCESSING
74
70
TAP 1
u(n)
TAP 2
u(n-1)
TAP 3
u(n-2)
TAP N
u(n-N)
*
*
*
*
COEFF. 1
ha(n,1)
COEFF. 2
ha(n,2)
COEFF. 3
ha(n,3)
COEFF. N
ha(n,N)
=
=
=
=
PROD. 1
P(1)
+
PROD. 2
P(2)
+
PROD. 3
P(3)
+
PROD. N
P(N)
x(n)

Fig. 5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28'
18'
52'
PROBE GENERATOR
40'
54'
50'
DELAY
SIGNAL PROCESSOR
32'
d(n)
DELAY
56'
FEEDBACK PATH
30'
e(n)
64'
ADAPTIVE FILTER
58'
x(n)
y(n)
48'
Ref.
USER OPERATED CONTROL
60'
DELAY
84
y'(n)
82
16'
62'
24

Fig. 6

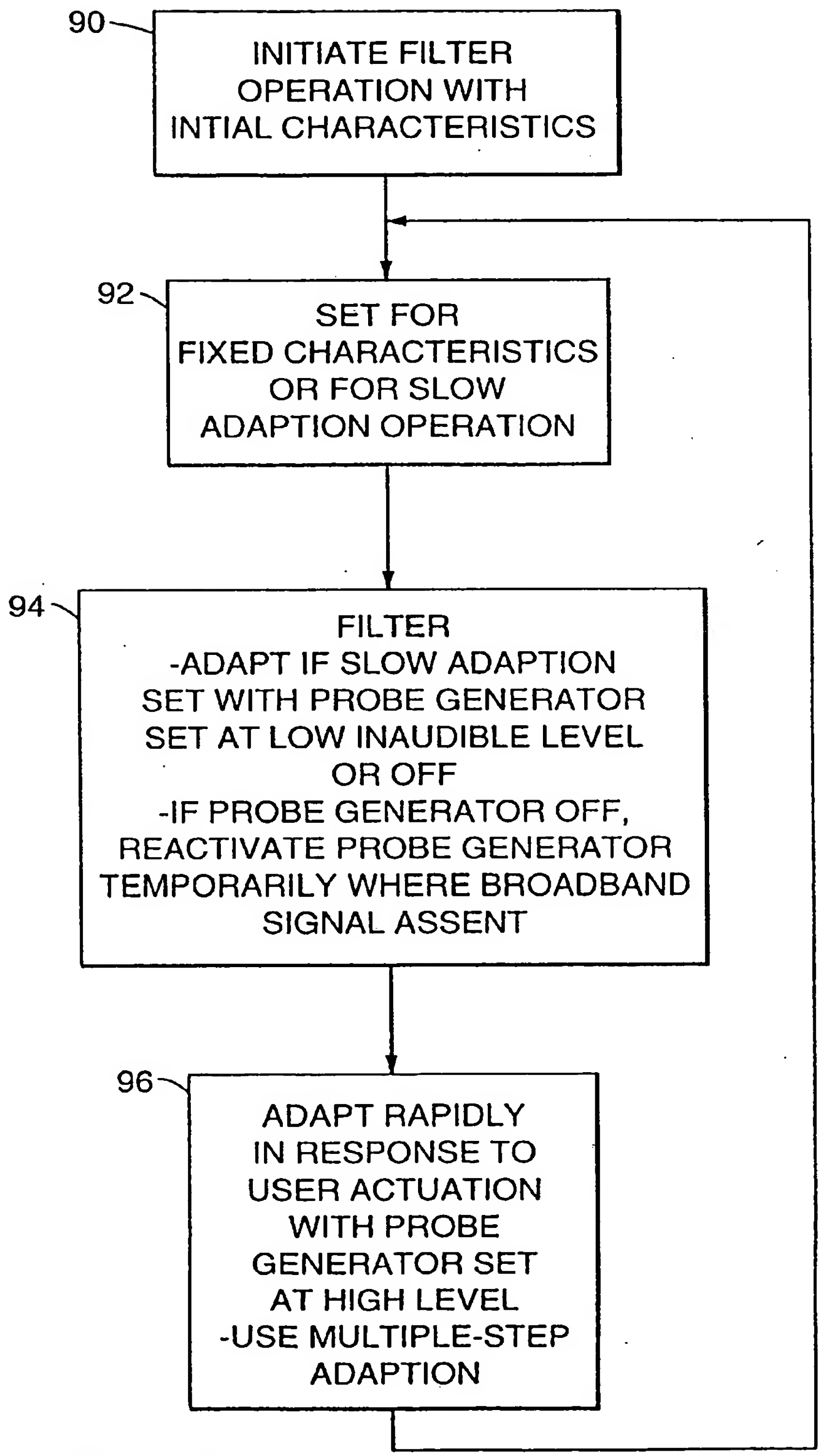
90
INITIATE FILTER OPERATION WITH INTIAL CHARACTERISTICS
92
SET FOR FIXED CHARACTERISTICS OR FOR SLOW ADAPTION OPERATION
94
FILTER -ADAPT IF SLOW ADAPTION SET WITH PROBE GENERATOR SET AT LOW INAUDIBLE LEVEL OR OFF -IF PROBE GENERATOR OFF, REACTIVATE PROBE GENERATOR TEMPORARILY WHERE BROADBAND SIGNAL ASSENT
96
ADAPT RAPIDLY IN RESPONSE TO USER ACTUATION WITH PROBE GENERATOR SET AT HIGH LEVEL -USE MULTIPLE-STEP ADAPTION

Fig. 7